On Classical dS Vacua in String Theory

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quest

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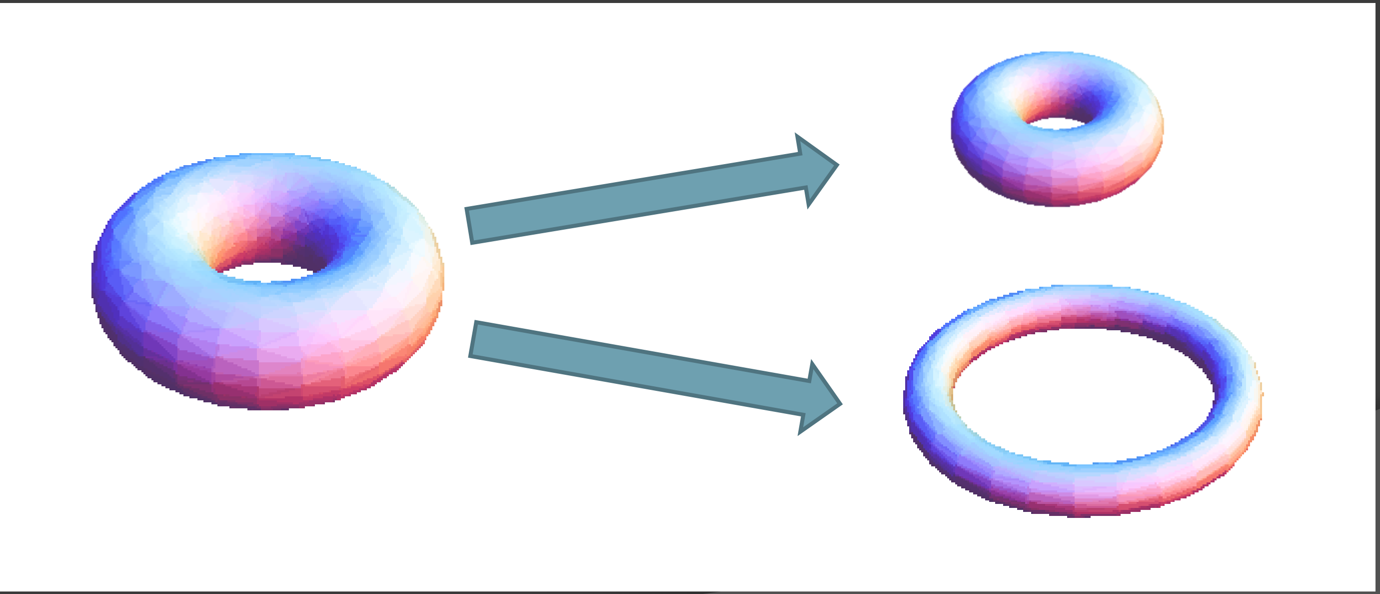
C. Caviezel, TW, M. Zagermann	0912.3287 [hep-th]
R. Flauger, D. Robbins, S. Paban, TW	0812.3886 [hep-th]
C. Caviezel, P. Koerber, S. Körs, D. Lüst, TW, M. Zagermann	0812.3551 [hep-th]
TW, M. Zagermann	1003.0029 [hep-th]

Outline

- Motivation
- Type II flux compactifications
- Search for dS vacua and slow-roll inflation in concrete type II models
- Conclusion and Outlook

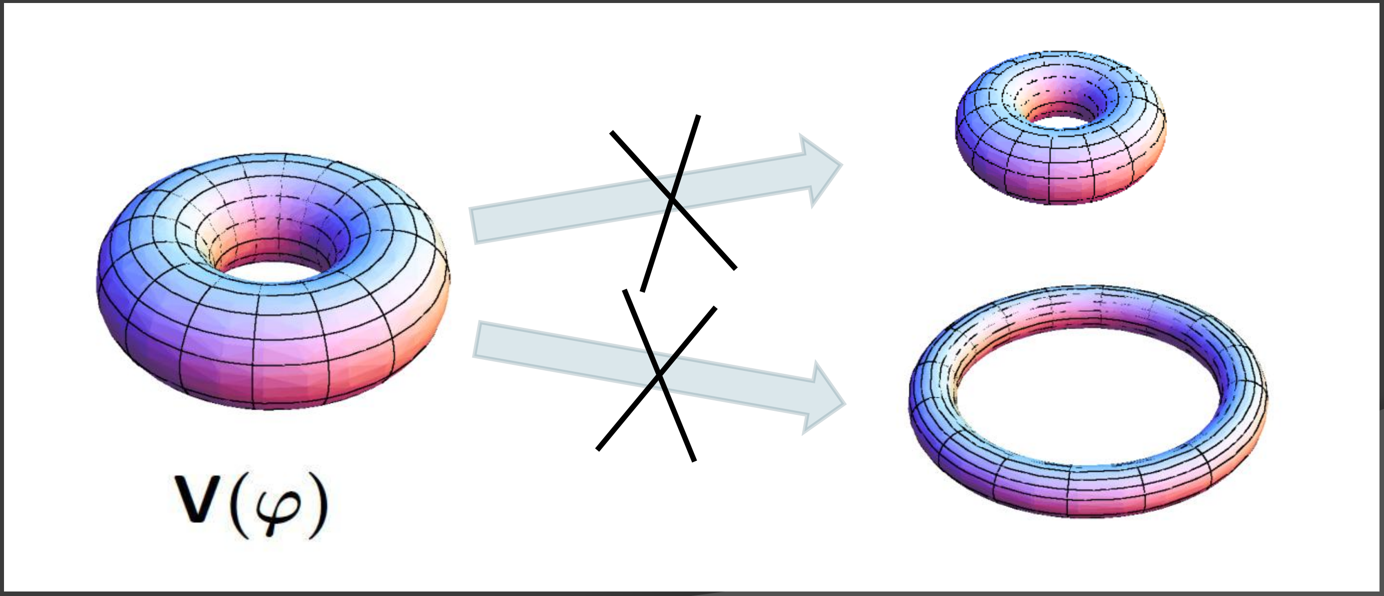
Motivation

- Supersymmetric compactifications of supergravity/string theory generically lead to massless scalar fields $\Rightarrow$ moduli problem



Motivation

- (NSNS and RR) Fluxes, orientifold planes and/or (non-) perturbative corrections stabilize string moduli



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- Interesting for cosmology:

  Does $V(\varphi)$ allow for dS vacua and/or inflation?

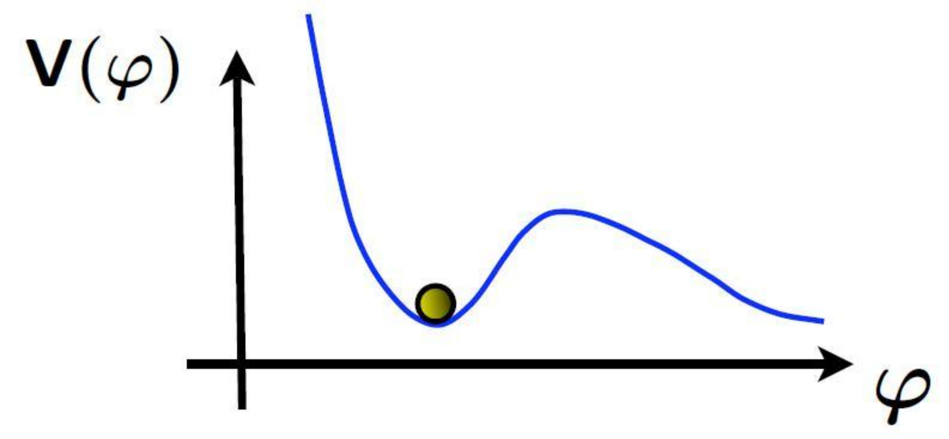
  What are the minimal necessary ingredients?

Motivation

dS vacuum requires

$$\varepsilon \sim (V'/V)^2 = 0$$

$$\eta \sim V''/V > 0$$



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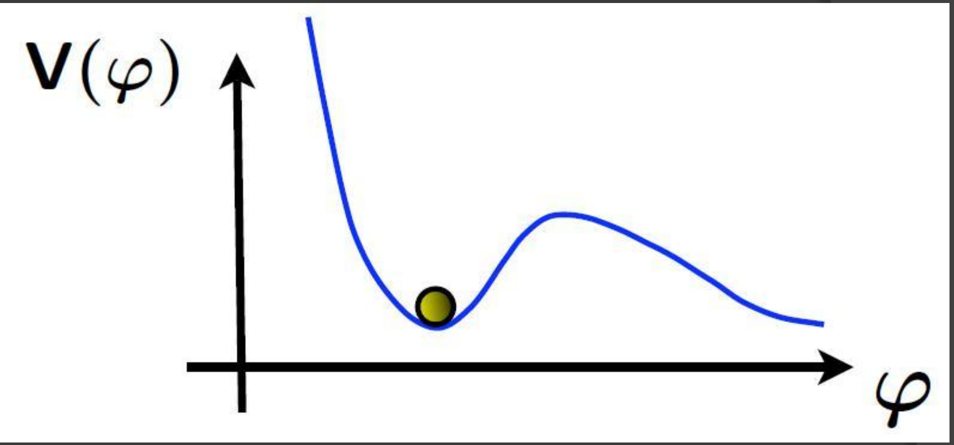
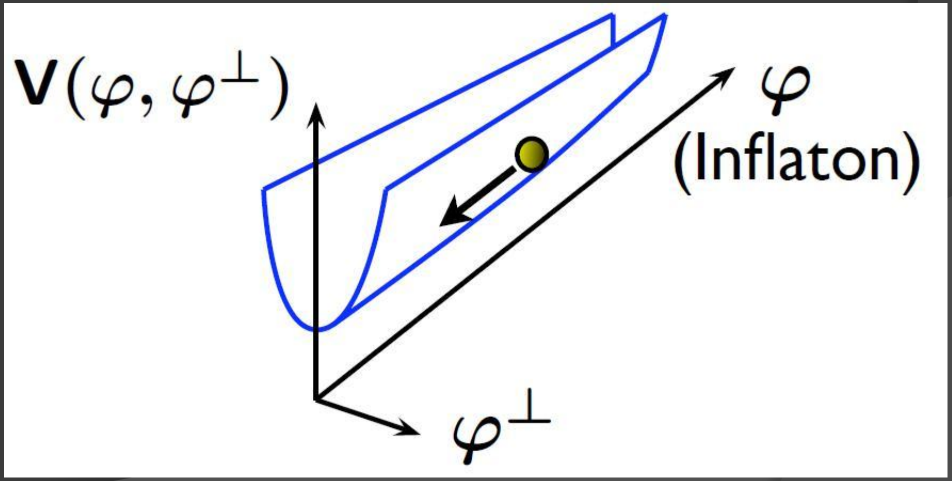


Inflation requires

$$\varepsilon \sim (V'/V)^2 << 1$$

$$|\eta| \sim |V''/V| << 1$$



Motivation

Can we find explicit compactifications that lead to fully stabilized dS vacua at tree-level?

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Need negative tension objects (O-planes)

Gibbons

deWit, Smit, Hari Dass

Maldacena, Nuñez

$\Rightarrow$ Type IIA/IIB string theory

Type II Flux Compactifications

Can we find explicit compactifications that lead to fully stabilized dS vacua at tree-level?

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$$\text{IIA}: \ p \in \{0,2,4,6\},\ q \in \{4,6,8\}, \qquad \text{IIB}: \ p \in \{1,3,5\},\ q \in \{3,5,7,9\}$$

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$$V = V_H + \sum_p V_{F_p} + \sum_q V_{Oq} + V_{R_6}, \qquad V_H, V_{F_p} \geq 0, \; V_{Oq} \leq 0$$

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Find a,b such that $(-a\tau\partial_\tau - b\rho\partial_\rho)V \geq cV, \quad c > 0.$

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no slow-roll: $\varepsilon = \frac{K^{i\bar{j}}\partial_i V \partial_{\bar{j}} V}{V^2} \geq \frac{c^2}{4a^2 + 3b^2} \approx O(1)$

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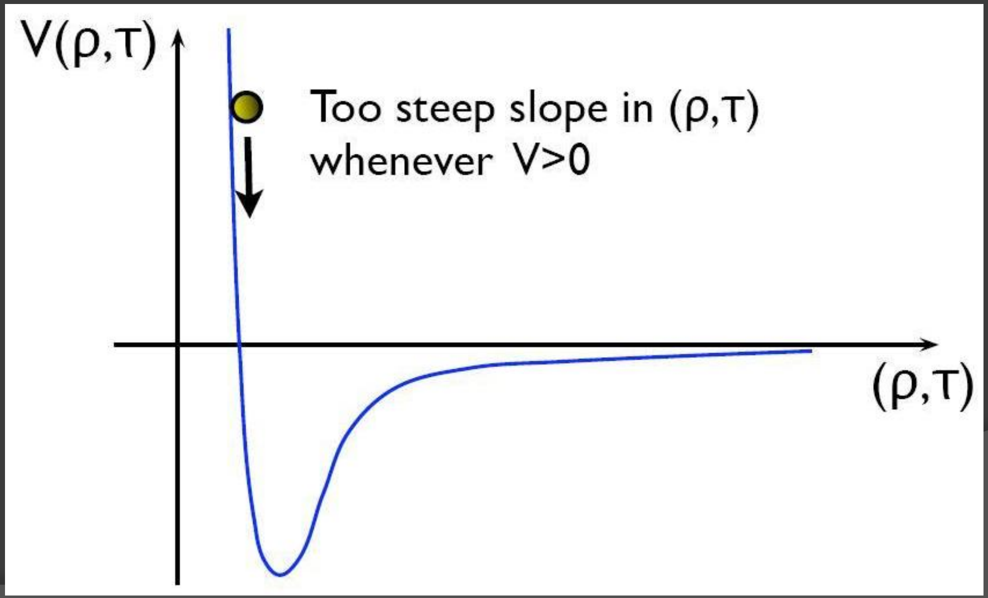

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Can find a, b such that $(-a\tau\partial_\tau - b\rho\partial_\rho)V \geq cV, \quad c > 0,$

- whenever $p+q-6 \geq 0, \ \forall p, q,$ for $V_{R_6} \propto -R_6 \leq 0.$
- whenever $p+q-8 \geq 0, \ \forall p, q,$[1)] for $V_{R_6} \propto -R_6 > 0.$

1) O3-planes with F_5-flux is also possible.

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Can we find explicit compactifications that lead to fully stabilized classical dS vacua?

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Minimal ingredients needed to evade no-go theorem in the (ρ,τ)-plane.

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Need low dimensional Oq-planes with low rank RR-fluxes.

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Spaces with negative integrated curvature favored.

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CY_3 has R_6=0: IIA with F_0, F_2, F_4, F_6, H, O6
IIB with F_3, H, O3

Hertzberg, Kachru, Taylor, Tegmark 0711.2512 [hep-th]

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$R_6=0$: Need 1-cycles/1-forms for O4-planes/F1-flux.

What about T^6 or $T^2 x K3$?

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F_0 flux needs to be odd under O4 orientifold projection.

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$F_{1/5}$ flux needs to be even under O3 orientifold projection.

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Curvature and O3 orientifold projection:

$$de^i = -\frac{1}{2} f^{\,i}_{jk} e^j \wedge e^k, \quad \sigma_{O3} : e^i \to -e^i \quad \Rightarrow \quad f^{\,i}_{jk} = 0$$

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Probably always one Kähler modulus unstabilized which leads to a runaway direction.

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Full moduli stabilization in principle possible!

Type II Flux Compactifications

Can we find explicit compactifications that lead to fully stabilized classical dS vacua?

Assumptions:

- Restrict to bulk moduli and neglect blow-up sector
- Restrict to the closed string sector (no D-branes)
- Take O-planes to be smeared over transverse directions
- Consider only compactifications that give a 4d $\mathcal{N} = 1$ action

Type II Flux Compactifications

Flux compactifications that give a 4d $\mathcal{N} = 1$ action

- CY_3 with O6, O3/O7 or O5/O9

Grimm, Louis hep-th/0403067, hep-th/0412277
DeWolfe, Giryavets, Kachru, Taylor hep-th/0505160
Hertzberg, Kachru, Taylor, Tegmark 0711.2512 [hep-th]

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- SU(3)-structure with O6, O3/O7 or O5/O9

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Danielsson, Haque, Shiu, Van Riet 0907.2041 [hep-th]
de Carlos, Guarino, Moreno 0907.5580, 0911.2876 [hep-th]
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de Carlos, Guarino, Moreno 0907.5580, 0911.2876 [hep-th]
Danielsson, Koerber, Van Riet 1003.3590 [hep-th]

- SU(2)-structure with O5/O7 or O4/O6/O8

C. Caviezel, TW, M. Zagermann 0912.3287 [hep-th]

SU(n)-structure manifolds, n=2,3

Calabi-Yau is special case of SU(n)-structure manifold

$\nabla\zeta = 0 \;\Rightarrow\; R_{mn} = 0 \;\Rightarrow\; V_{R_6} = 0 \;\Rightarrow$ No-go theorem

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We need non-Calabi-Yau:

$$\nabla\zeta \neq 0 \;\Rightarrow\; R_{mn} \neq 0 \;\Rightarrow\; V_{R_6} \neq 0 \;\Rightarrow$$ dS? Slow-roll?

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Problem: What are the relevant light fields?

CY_3: $J_{mn} = i\zeta_+^\dagger \gamma_{mn} \zeta_+$ $\quad \Omega_{mnp} = \zeta_-^\dagger \gamma_{mnp} \zeta_+$

$\nabla\zeta = 0 \;\Rightarrow\; dJ, d\Omega = 0 \;\Rightarrow\;$ Expand in harmonic forms

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$$\boxed{\nabla \zeta \neq 0 \;\Rightarrow\; dJ, d\Omega \neq 0}$$ Expansion basis, moduli?

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- Generic case not understood

Kashani-Poor, Minasian hep-th/0611106

Graña, Louis, Waldram hep-th/0612237

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- Examples of SU(n)-structure manifolds include twisted tori and coset spaces G/H

Dabholkar, Hull, Reid-Edwards
Cvetic, Liu, Schulz
Robbins, Ihl, TW
Graña, Minasian, Petrini, Tomasiello
Caviezel, Koerber, Körs, Lüst, Tsimpis, Zagermann

- Natural expansion basis exists: G invariant forms

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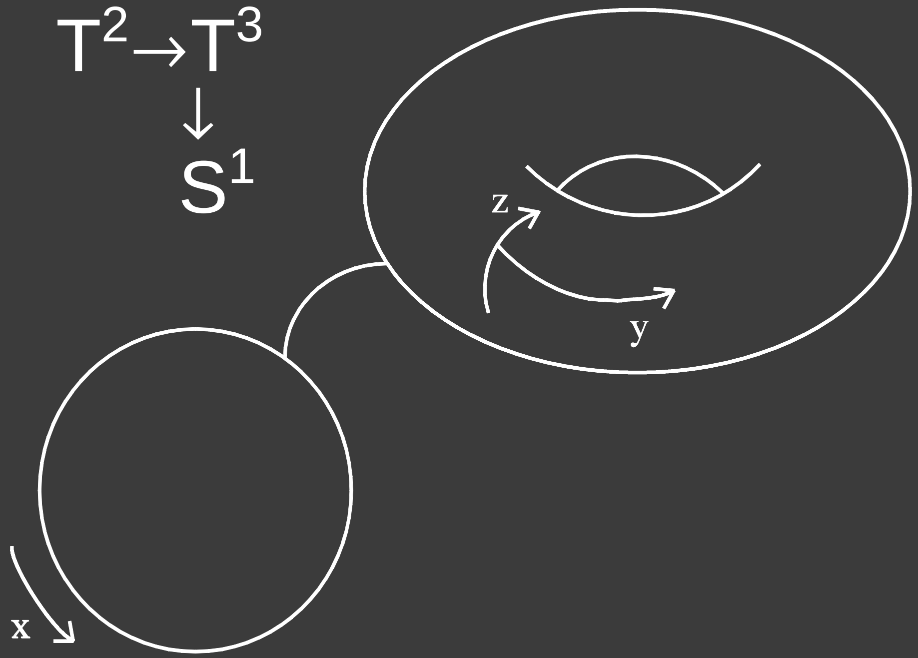
- Natural expansion basis exists: G invariant forms
- Models expected to be consistent truncations ($\Rightarrow$ potential instability in other sector)

Cassani, Kashani-Poor 0901.4251 [hep-th]

Generalized NSNS-flux: H-flux

$$T^2 \to T^3$$
$$\downarrow$$
$$S^1$$



$$ds^2 = dx^2 + dy^2 + dz^2$$

$$x, y, z \sim x, y, z + 1$$

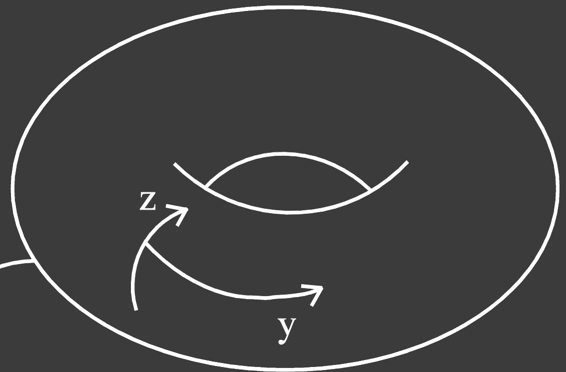
$$H = N dx \wedge dy \wedge dz$$

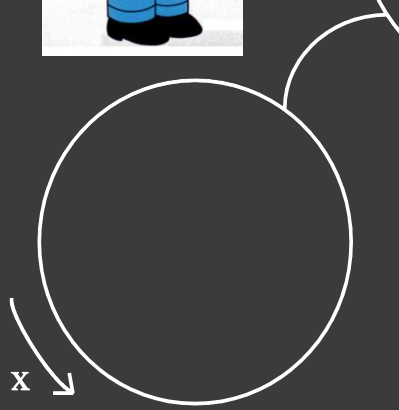
$$\int_{T^3} H = N$$

$$B = N x dy \wedge dz$$

If we go around the base $x \to x + 1$, the B-field on the fiber gets shifted $B_{yz} \to B_{yz} + N$.

Generalized NSNS-flux: (geo) metric flux





T-duality along z:

$$B = 0 \;\Rightarrow\; H = 0$$

$$ds^2 = dx^2 + dy^2 + (dz + Nx\,dy)^2$$

If we go around the base $x \to x+1$, the fiber gets twisted $y \to y, z \to z - Ny$.

Generalized NSNS-flux: (geo) metric flux

- The new space is not a torus anymore. It is often called twisted torus.
- It has the global 1-forms

$$e^x = dx, \;\; e^y = dy, \;\; e^z = dz + Nxdy.$$

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- The H_{ijk}-flux got turned into "metric flux" $f^{\,i}_{jk}$ defined by $de^i = -\frac{1}{2} f^{\,i}_{jk} e^j \wedge e^k$.
- We expand our fields and fluxes in terms of the e^i so that they won't be closed anymore.

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- The H_{ijk}-flux got turned into "metric flux" $f^{\ i}_{jk}$ defined by $de^i = -\frac{1}{2} f^{\ i}_{jk} e^j \wedge e^k$.
- We expand our fields and fluxes in terms of the e^i so that they won't be closed anymore.
- The twisted torus is not Ricci flat but has $R_3 = -\dfrac{N^2}{2}$.

Type IIA on SU(3)-structure

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but concrete models have many more directions:

$$V = V(\tau, \rho, \varphi^{\perp})$$

Are there refined no-go theorems involving the $\varphi^{\perp}$?

Type IIA on SU(3)-structure

New no-go theorems using other directions in moduli space?

For example models with factorization of Kähler sector:

$$vol_6 = \kappa_{abc} k^a k^b k^c = k^0 \tilde{\kappa}_{de} k^d k^e = vol_2 \cdot vol_4, \quad d,e \neq 0$$

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Idea:

$$V(\tau, \rho, \ldots) \to V(\tau, k^0, k^d, \ldots)$$

Are there refined no-go theorems using the

τ, k^0, k^d- directions? Under what assumptions?

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and restrictions on curvature ("metric fluxes"), e.g.

$$J = k^0 w_0 + k^d w_d$$

$$dw_0 = 0,\, dw_d \neq 0: \; -\tau \partial_\tau V - k^0 \partial_{k^0} V \geq 3V \;\Rightarrow\; \varepsilon \geq \frac{9}{5},$$

$$dw_0 \neq 0,\, dw_d = 0: \; -2\tau \partial_\tau V - k^d \partial_{k^d} V \geq 6V \;\Rightarrow\; \varepsilon \geq 2.$$

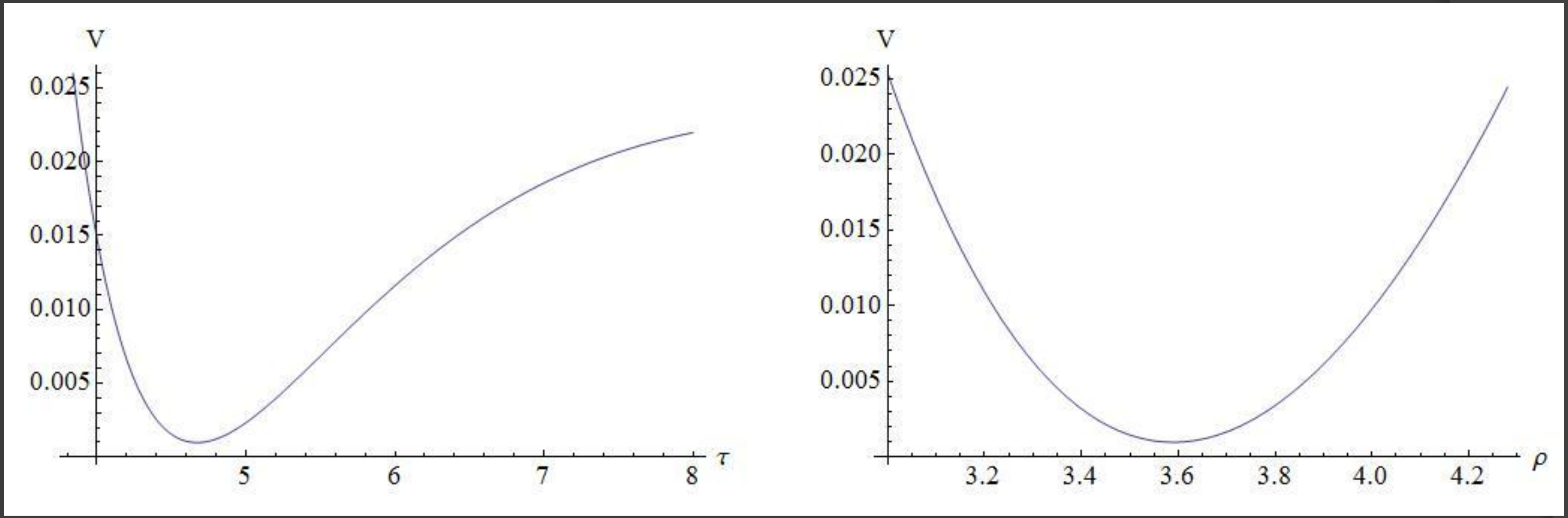
Flauger, Robbins, Paban, TW 0812.3886 [hep-th]
Caviezel, Koerber, Körs, Lüst, TW, Zagermann 0812.3551 [hep-th]

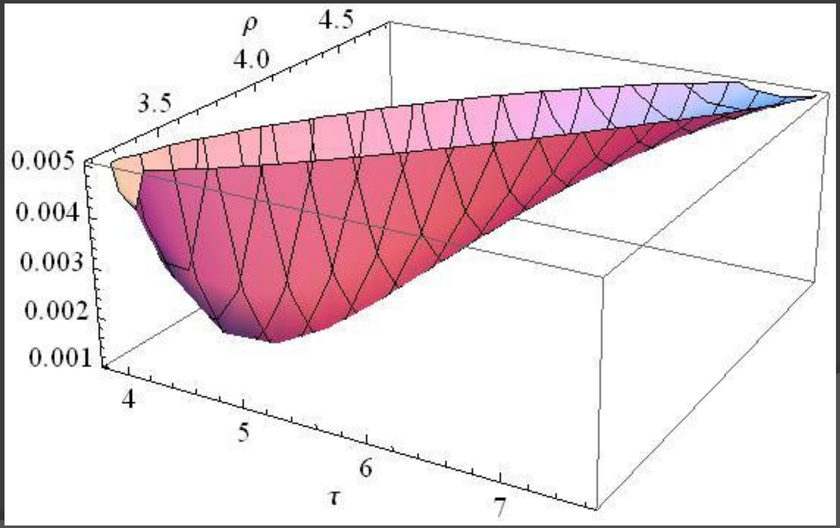
Type IIA on SU(3)-structure

New no-go theorems using other directions in moduli space:

- Exclude almost all models (6 cosets, 10 twisted tori) that were studied
- Ť^6/Z_2xZ_2 and S^3xS^3/Z_2xZ_2 evade all known no-go theorems. Numerically we indeed find $\varepsilon \approx 0$!

Type IIA on $S^3 x S^3$





Type IIA on SU(3)-structure

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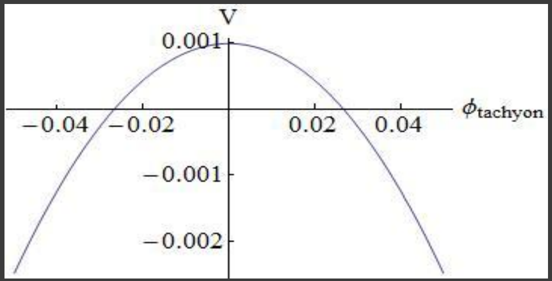

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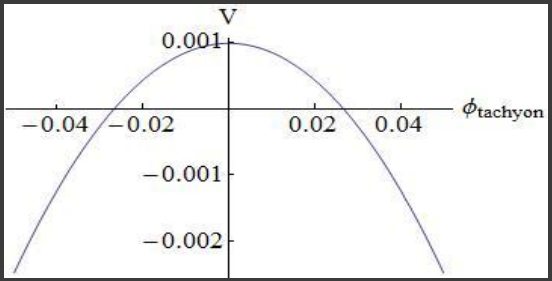

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Covi, Gomez-Reino, Gross, Louis, Palma, Scrucca 0804.1073 [hep-th]
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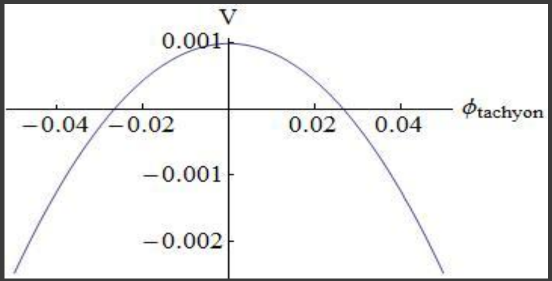

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- dS extremum for S^3xS^3/Z_2xZ_2 lifts to 10d

Danielsson, Koerber, Van Riet 1003.3590 [hep-th]

Type IIB on SU(2)-structure

- SU(2)-structure compactifications with O5/O7 orientifold projections $\Rightarrow \mathcal{N}=1$ in 4d
- SU(2)-structure manifolds have 1- and 5-forms $\Rightarrow$ RR fluxes F_1, F_3, F_5 for IIB

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- Can stabilize all moduli at tree-level in a super-symmetric AdS vacuum with large volume and small string coupling

Caviezel, TW, Zagermann 0912.3287 [hep-th]

Type IIB on SU(2)-structure

Type IIB on $T^2 x T^4/Z_2$ with O5-planes and O7-planes SU(2)-structure

	T^2		T^4/Z_2			
O-plane	1	2	3	4	5	6
O5			X	X		
O5					X	X
O7	X	X	X		X	
O7	X	X		X		X

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↕ T-duality

Type IIA on $T^6/Z_2 x Z_2$ with

O6-planes

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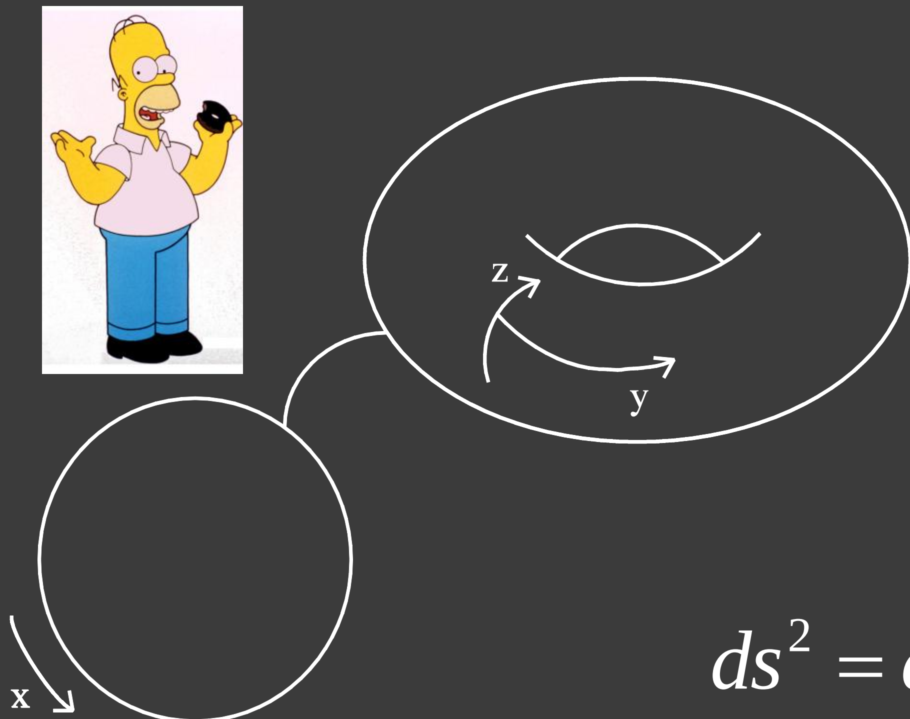
Generalized NSNS-flux: (geo) metric flux



T-duality along z:

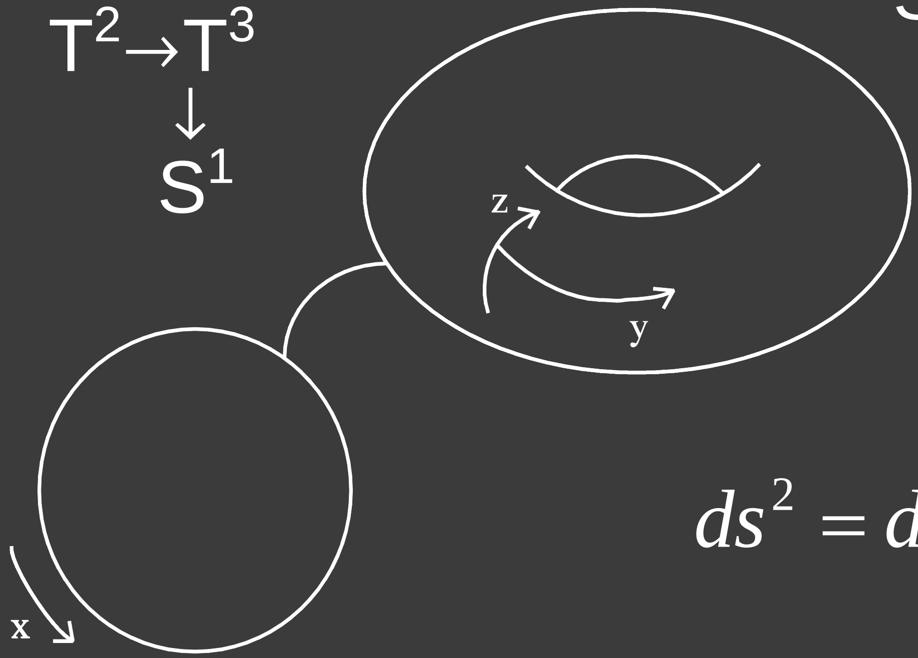
$$B = 0 \Rightarrow H = 0$$

$$ds^2 = dx^2 + dy^2 + (dz + Nx\,dy)^2$$

If we go around the base $x \to x+1$, the fiber gets twisted $y \to y, z \to z - Ny$.

Generalized NSNS-flux: non-geometric flux

$T^2 \rightarrow T^3$
$\downarrow$
S^1



Second T-duality along y:

$$B_{yz} = \frac{Nx}{1+N^2x^2}$$

$$ds^2 = dx^2 + \frac{1}{1+N^2x^2}(dy^2+dz^2)$$

If we go around the base $x \rightarrow x+1$, g and B are not periodic in any obvious sense. The space is only locally geometric but not globally.

Type IIB on SU(2)-structure

T-dual to SU(3)-structure but might lead to new examples:

- SU(3)- and SU(2)-structure spaces have metric-flux
- T-duality might lead to non-geometric spaces

  $\Rightarrow$ supergravity applicable in T-dual description?

Wecht 0708.3984 [hep-th]

- SU(2)-structure compactifications not T-dual to *geometric* SU(3)-spaces are new

Type IIB on SU(2)-structure

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Type IIB on SU(2)-structure

- Only very few cosets and twisted $T^2 x T^4 / Z_2$
- Natural split of Kähler and complex structure moduli:

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- Can derive no-go theorems to exclude dS vacua and slow-roll in several concrete examples
- $S^3 x S^3$ example again evades all no-go theorems. Numerically we indeed find $\varepsilon \approx 0$ but $\eta \approx -3$.

Caviezel, TW, Zagermann 0912.3287 [hep-th]

Conclusions

- General no-go theorems against tree-level dS vacua and slow-roll inflation exists
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Conclusions

- General no-go theorems against tree-level dS vacua and slow-roll inflation exists
- Negative curvature spaces more promising
- Type IIA on SU(3)-structure with O6-planes and type IIB on SU(2)-structure with O5/O7-planes allow for stabilization of all closed string moduli
- Many no-go theorems for explicit examples
- Can find explicit numerical dS extrema but only with one tachyonic direction

Outlook / Future research

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Villadoro, Zwirner hep-th/0602120
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THANK YOU!